

## **APPENDIX 1**

### **Public and Peer Review Panel Comments**

#### **Appendix 1-2**

##### **Comments from the Public and Consultants**

#### **Appendix 1-2d**

##### **Exponent's Comments and Letters of Transmittal to Chapter 7 and Risk Assessment**

<b>A1-2d</b>	Exponent's March 31 <sup>st</sup> Comments on Chapter 7 of the 2000 Everglades Consolidated Report.....	Page A1-2d-1
<b>A1-2d</b>	Exponent's June 29 <sup>th</sup> Letter Summarizing Previous Comments on Chapter 7 of the 2001 Everglades Consolidated Report...	Page A1-2d-16
<b>A1-2d</b>	Exponent's August 18 <sup>th</sup> Risk Assessment for Consideration as Comments to the 2001 Everglades Consolidated Report.....	Page A1-2d-19

\*Please note that the technical memorandum is an expanded report based on the overheads of the presentation submitted to the District on June 29, 2000 for consideration in the 2001 Everglades Consolidated Report. Due to the importance of the material in regards to the mercury problem, the August submission has been included in this appendix.

## **Comments on Chapter 7 of the South Florida Water Management District's 2000 Everglades Consolidated Report**

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After reviewing the South Florida Water Management District's *2000 Everglades Consolidated Report* (SFWMD 1999), Exponent wishes to make a few comments to improve the quality of the upcoming 2001 report. Generally, we feel that the District needs to exercise greater care in both its data interpretation and hypothesis testing, and should much more clearly represent the uncertainties associated with its conclusions. In six specific areas, we feel that the District's position could be greatly improved with more substantial analysis or more objective hypothesis testing. These areas are detailed in the following sections.

### **Water Column Phosphorus Concentrations**

One of Exponent's major concerns is the approach the District tends to take in addressing matters such as mercury fate and transport. In general, the presentation is a holistic exercise in deductive logic. Although this is appropriate for the generation of scientific hypotheses, it is contrary to scientific method to use it to develop conclusions. Conclusions must be based on tested hypotheses, using rigorous scientific and statistical analyses. Therefore, we request that the 2001 report take a more objective and less advocative position by presenting the products of the deductions as hypotheses, not as conclusions.

One example is the suppositions on pages 7-37 to 7-38 concerning the role of dissolved oxygen concentrations in mercury methylation. Analysis of EPA's Environmental Monitoring and Assessment Program (EMAP) database indicates no relation between dissolved oxygen and methylmercury concentrations in the water in the Everglades (Attachment 1). The examples that the District cites as supportive are related to deep-

water lakes, not wetlands representative of the Everglades. Exponent requests that the District present specific data supporting its position and refuting the findings observed in the EMAP database.

## Inverse Relationship with Phosphorus

The District has laudably begun to take a mechanistic approach in looking at the potential relation between eutrophication and methylmercury bioaccumulation. Exponent would have liked an opportunity to comment on this material during the review process, but it was not presented in the review drafts.

A general concern with the 2000 report that Exponent would like to see remedied in the 2001 report is the dependence of the District's arguments on personal communications. In the sections on inverse relationships alone, this occurred eighteen times. Such hearsay cannot be considered evidence because it has not been subjected to validation or peer review. We therefore request, for the 2001 report, that any time the authors must rely on unpublished data, they make those data available for review either within the chapter or in an appendix.

In the 2000 report, the district deduced (based on no testable evidence) that the acknowledged, demonstrable inverse relation between phosphorus concentrations in water and methylmercury bioaccumulation has no causal basis. The District bases this position on three suppositions. First, it is assumed that macrophyte productivity in eutrophic areas is nearly twice that in the oligotrophic portions of WCA-2A as the result of increased phosphorus inputs. Second, although macrophytes clearly demonstrate increased productivity and reduced mercury concentration along the phosphorus gradient, their capacity to store and turn over mercury is assumed to be insignificant with regard to total mercury fluxes. Third, it is assumed that the higher productivity of periphyton in the nutrient-poor regions of the Everglades (and lower productivity in eutrophic regions due

to macrophyte shading) and the associated high mercury concentrations are solely responsible for higher mercury concentrations in the oligotrophic food chain.

Following the District's reasoning, the District's actions in removing phosphorus from the Everglades inflows will reduce macrophyte densities and concurrently increase periphyton densities in the northern parts of WCA-2A. This will spread conditions conducive to high mercury concentrations in the food web since the ecosystem found in the south will replace the ecosystem now found in the north. One would then expect that as restoration progresses, the direct result of the District's actions will be to increase the risk of adverse effect to Everglades wildlife from exposure to mercury. If the District wishes to stand by this position, Exponent requests that all of its ramifications, both present and future, be fully outlined in the 2001 report.

## Mercury Flux Models

The discussion of mercury in periphyton wrongly focuses on normalized periphyton concentrations and total mercury cycling (page 7-55). The use of mercury concentration in periphyton to discount the biodilution hypothesis is poorly grounded. The "coverage weighted" values for periphyton concentrations obscure the fact that total biomass is much larger in the eutrophic zones, and thus total mercury should be more diluted. Biodilution occurs as the average mercury concentration decreases in response to an increase in overall biomass, and higher total mercury concentration in a single type of biota (periphyton) does not break the "'classical' link between eutrophication and biodilution," and does not prove that "the oligotrophic site has a higher biodilution factor than the eutrophic sites." If the District wishes to prove this hypothesis, Exponent would like to see a demonstration that overall *methylmercury* concentration in biota is lower in the biomass of oligotrophic versus eutrophic sites. This is currently outside the scope of the District's supposition because the ecological model poorly represents the productivity of the eutrophic regions of the Everglades. To balance the model, Exponent requests that in its 2001 report the District amend its mercury flux models to include other food

sources such as non-periphyton algae, and benthic and water column hetrotrophs, as well as benthic infauna. Furthermore, the District should validate its logic using small resident fish such as *Gambusia*, which would be the true test of its suppositions.

Aside from the error in logic and the unbalanced ecological model, there are several basic premises put forth as supportive that Exponent would like to see substantiated in the 2001 report. First, Grimshaw et al. (1997), the only reference provided by the District to support its arguments, only measured light availability during “the warmer seasons of the year.” This would be the time of maximum *Typha* growth in the eutrophic regions and maximum periphyton growth in the oligotrophic regions. Exponent would appreciate any evidence that this relation holds for the remaining three-quarters of the year.

Second, overgeneralization has resulted in the District’s assumption that ionic mercury and methylmercury behave similarly throughout the environment. This is often not the case. For example, it has been shown that higher plants preferentially take up and accumulate methylmercury to a greater extent than ionic mercury (Huckabee and Blaylock 1973). If we assume, as the District does, that the “total mercury” in the macrophytes is ionic in nature, then it does in fact account for a small portion of the total spatial flux within the Everglades. However, if the measured total mercury concentration in the macrophytes represents disproportionately higher concentrations of methylmercury, it may well represent a highly significant pathway for the introduction of methylmercury into the food chains. Therefore, Exponent requests that in the 2001 report the District provide the following:

1. Consideration of the relationship between productivity and nutrient balance for the entire year, not just a small part of the year
2. The data on which the analysis in Table 7-1 was performed
3. The distributions from both the eutrophic and oligotrophic regions (rather than generalizing thousands of acres with a single number)

4. Analyses of ionic mercury and methylmercury separately in their models, to test this flux hypothesis.

## Relationship of Mercury to Sulfur Cycling

Heavy reliance on personal communications appears again in the District's discussion of the role of sulfate in mercury cycling. For example, the observation that the absence of sulfate "is not always associated with inactivity by SRB" is key to the discussion of methylation, yet is supported only by informal communication from Cindy Gilmour. More importantly, the reference to demethylation by aerobic bacteria, SRB, and methanogens is probably the most important component in understanding net methylation rates; yet the only citation is a personal communication from R. Orm, USGS. Exponent again requests that if peer-reviewed evidence is not available to substantiate the District's arguments, then the District present data upon which these premises are based in the 2001 report.

Overall, Exponent feels that the validity of the sulfur hypothesis is tenuous at best. The discussions regarding mercury methylation and demethylation are not connected, as they must be because net methylation is the principal parameter that correlates with food web concentrations. For example, the discussion on the bottom of page 7-57 takes great care to describe the parabolic relationship between sulfate concentration and net methylmercury production. However, this is based on what is described as "a moderate inverse relationship" between sulfate concentration and methylmercury in soil. The District expresses confidence that the peak net methylation rate, as well as mercury concentrations in sediment, water, and biota, can be predicted from the optimal ratio of sulfate to sulfide in pore water. However, while the high methylation rates at WCA-2B S might be explained by sulfate/sulfide ratios, this does not explain why other regions of the Everglades with similar sulfate/sulfide ratios do not show the same levels of methylmercury production and bioaccumulation (see page 7-59). The relationship at WCA-2B S appears to be correlation, not causation. Furthermore, the District's

supposition that groundwater flow, or wetting and drying cycles, or mercury deposition rates may override the importance of the sulfate/sulfite ratios only emphasizes the weakness in the model (i.e., it has failed to capture the key environmental factors involved in the regulation of net mercury methylation).

## **Probabilistic Risk Assessment (Appendix 7-3b)**

The District is now on the right track in using probabilistic analyses to predict potential risk to wading birds. However, we are concerned with several aspects of the analyses, not least of which is the poor documentation. The District's explanation of its methodologies is extremely terse; there also references cited in the text that are not provided in the reference section. Exponent would like to see these gaps remedied in the 2001 report. We recommend that the District consult EPA's draft probabilistic guidance (U.S. EPA 1999) for the proper way to present methodologies for this type of analysis.

Probabilistic risk assessment analysis has two major strengths over determinant methodologies. First, it permits the transparent demonstration of uncertainty associated with the assumptions. Second, it permits inferences as to the statistical magnitude of population impacts expected as the result of modeled exposures. Unfortunately, the District neglected to take advantage of either of these strengths. Furthermore, because the District did not follow through on the appropriate analyses, there is no way to validate their accuracy, and, therefore, their estimates cannot be accepted. Specific criticisms are given in the following paragraphs.

### **Lack of Distribution Testing**

Just as with determinant analysis, it is the responsibility of the risk assessor to substantiate all inputs into the probabilistic risk model. Because the inputs in this case are distributions, it is necessary to ensure that the distributions are representative of the

data. When assumptions are made that empirical data can be represented by a standard statistical model (e.g., normal, lognormal, delta), it is necessary to determine the goodness of fit. Otherwise, the assumptions are unsubstantiated. Exponent would like to see goodness-of-fit analyses in the 2001 report before we can give credence to the risk assessment. There are numerous methods of testing goodness of fit, and the District is directed to Fishman (1996) for appropriate guidance. A better method when dealing with substantial databases is to use assumption-free distributions. Guidance on this is available from U.S. EPA (1999).

### Improper Model Execution

Exponent was able to replicate the analysis for two receptors reported by the District, although this was very difficult because of the lack of documentation. We found an error in the method, which draws the validity of the results into serious question. The District stated that its base model was as follows:

$$ADD_{pot} = \frac{\sum_{p=1}^p IR \times D_p \times [Hg]_p}{BW}$$

However, to make the model replicate the reported results, it had to be modified to the following:

$$ADD_{pot} = \frac{\sum_{p=1}^p IR \times \frac{D_p}{\sum_{p=1}^p D_p} \times [Hg]_p}{\frac{1}{BW}}$$

To account for the entire dietary intake, the proportional parameters must sum to 1 (i.e., 100 percent). Because the distributions used to estimate proportional intake of a given species of fish ( $D_p$ ) were considered independent, they had to be standardized to

fulfill the proportional constraint. This is a classic mistake in probabilistic risk assessment (i.e., treating dependent variables as being independent); it results in a shift of all estimates of proportional fish intakes toward the median. To illustrate, in the case of the great blue heron, an input distribution is provided that describes the likelihood of the diet being composed of 100 percent bass. This probability should be reflected in the risk analysis. However, by using this standardization, the probability that the heron is assigned a diet of 100 percent bass is equal to the probability of 100 percent bass in the diet *times* the probability of zero percent for warmouth *times* the probability of zero percent for *Lepomis* *times* the probability of zero percent for shiner. Exponent would like to see these serious errors corrected in the 2001 report, and again we direct the District to Fishman (1996) for guidance.

### **Lack of Consideration for Correlation**

When dealing with distributions in a Latin Hypercube simulation, it is vital that all distributions be independent. If not, potential correlations are not accounted for in the selection process. In ecological risk assessment, correlations may be very difficult to estimate. The prudent action in such cases is to narrow the definition of the population being modeled. The District did not observe this caveat. By assigning bird mass as an independent variable, the District neglected the correlation, noted by Krebs (1974), that larger herons tend to eat larger fish. Furthermore, the District's model explicitly requires that fish size be independent of fish type (i.e., the size distribution of the bass population is identical to the size distribution of the shiner population). The District also overlooked the correlation between heron size and species of fish eaten; this error can produce very large changes in the predicted distributions, particularly when using lognormal distributions. Therefore, Exponent would like to see the District provide statistical proof in the 2001 report that either a) all relationships modeled in the risk assessment are independent, or b) correlations are too poor to significantly impact the estimated risks.

### **Lack of Confidence Limit Reporting**

First-order Monte Carlo analysis provides a precise demonstration of the proportional variance within the defined distributions. However, it cannot represent the variance about the distributions; to demonstrate this type of uncertainty requires second-order Monte Carlo analysis using the standard errors of the empirical estimators. This type of analysis was overlooked by the District and is akin to reporting the means without providing the appropriate confidence limits. Exponent has consistently requested that the District provide adequate statistical representation of reported parameters. We again request that the District, in the 2001 report, provide the measure of bias in the probabilistic analysis by reporting the second-order confidence limits on the risk estimates.

### **Inappropriate Regional Comparisons**

Notably absent in the scenarios presented by the District was the current risk to wading birds at WCA-2A F1, the region that will be most impacted by the District's actions. To properly represent the risk associated with the District's activities, Exponent requests that this region be assessed in the 2001 report such that it may be compared to the District's forecasts.

### **Improper Result Interpretations**

Subjective interpretation based on objective analyses still equates to subjective conclusions. The District's analysis of the results of its probabilistic risk assessments is based on the assumptions that a) mercury cycling in the northern parts of WCA-2A, including the F1 station, is identical to that in WCA-2A U3 and b) that the conditions at WCA-2A will not change when phosphorus input is reduced to less than 10 ppb. Both assumptions are baseless and, by the District's own mercury modeling exercises, likely untrue. Associated with this subjective position is the conclusion that more than one-fifth

of the great blue heron population is at risk for some form of reproductive failure (based on exposures at WCA-2A U3). Exponent is concerned that a population of a wildlife receptor, such as the great blue heron, that possesses a 3-year maturation cycle cannot endure this level of reproductive failure without requiring recruitment from outside populations. By dramatically increasing the area for this type of impact (i.e., increasing the risks predicted at WCA-2A to the entire WCA-2A region), the District inevitably increases the pressure on surrounding heron populations to the extent of running a severe risk of local extinction events within the Everglades. Before the District pronounces that this magnitude of impact is “acceptable,” Exponent requests that the 2001 report provide the appropriate metapopulation analysis on wading birds indigenous to WCA-2A, both present and projected. This is the only way the District can ensure the public that what it considers an “acceptable” level of impact will not result in reproductive pressures that the regional populations are unable to withstand.

### **Historical Trends of Mercury Concentrations in Everglades Fish and the Feathers and Eggs of Wading Birds**

As Exponent commented previously (Exponent 1999), Chapter 7 of the 2000 report states in many places that mercury concentrations are declining in fish as well as in the eggs and feathers of wading birds. The District places great importance on this observation, and rightly so because it is an important indicator of the health of Everglades wildlife. However, Exponent remains unconvinced that the reported observations are real because the District has not performed the appropriate statistical analysis on the data sets provided by Frederick et al. (1997) and Lange et al. (1993). Furthermore, in our earlier comments Exponent analyzed the same data sets used in the 2000 report and demonstrated, based on multiple Studentized t-tests, that there was no significant difference with time in the concentrations of mercury in the prey fish for the wading bird receptors. We could not perform the same analysis on the egg and feather data because the District failed to provide the data in a timely manner.

To support the District's conclusion that mercury concentrations in fish, egret feathers, and egret eggs are indeed declining, Exponent requests the District to include in the 2001 report a proper hypothesis testing with rigorous statistical analysis of these data sets. This should include factorial analysis of variance to ensure that the differences in the mean represent a true trend, as well as covariance analysis to ensure that circumstances such as time of year of collection, size of fish, or location of nesting sites have not biased the results.

## **Selection of Sensitive Receptors**

The 2000 report focuses almost exclusively on wading birds as the most sensitive receptors in the Everglades. The report states, without supporting data, that mercury concentrations have been declining in the Florida panther. It also states that the American alligator and the river otter may be at risk, but that the risks are insignificant. Exponent provided a probabilistic analysis for both the river otter and the Everglades mink (a state-designated threatened species), using FFWCC's fish database, in our earlier comments (Exponent 1999). The results indicate, not only that the impact may be significant, but also that these piscivorous mammals may be the most sensitive receptors in the Everglades ecosystem.

Rather than modeling risk based on exposure concentrations based on exposure, the District reported in the 2000 report that it intends to use pharmacokinetics to determine the risk to mammalian receptors. Exponent applauds this endeavor but notes that no one else has ever succeeded at estimating risk to wildlife receptors in their natural environment using this approach. The inherent natural variation in the measures prescribed in the District's methodologies will require a large number of replications in order to provide acceptable limits of confidence. The data and understanding from what promises to be a massive undertaking will be a great aid to ecological risk assessment in general. Exponent is looking forward to progress reports in the 2001 report.

## Summary

In conclusion, Exponent advises the District to exercise greater care in both data interpretation and hypothesis testing by refraining from drawing conclusions based on speculation, by providing clearer acknowledgement and representation of statistical uncertainty, and by conducting proper hypothesis testing prior to presenting inferences as fact. Specific requests for inclusion in the 2001 report are as follows:

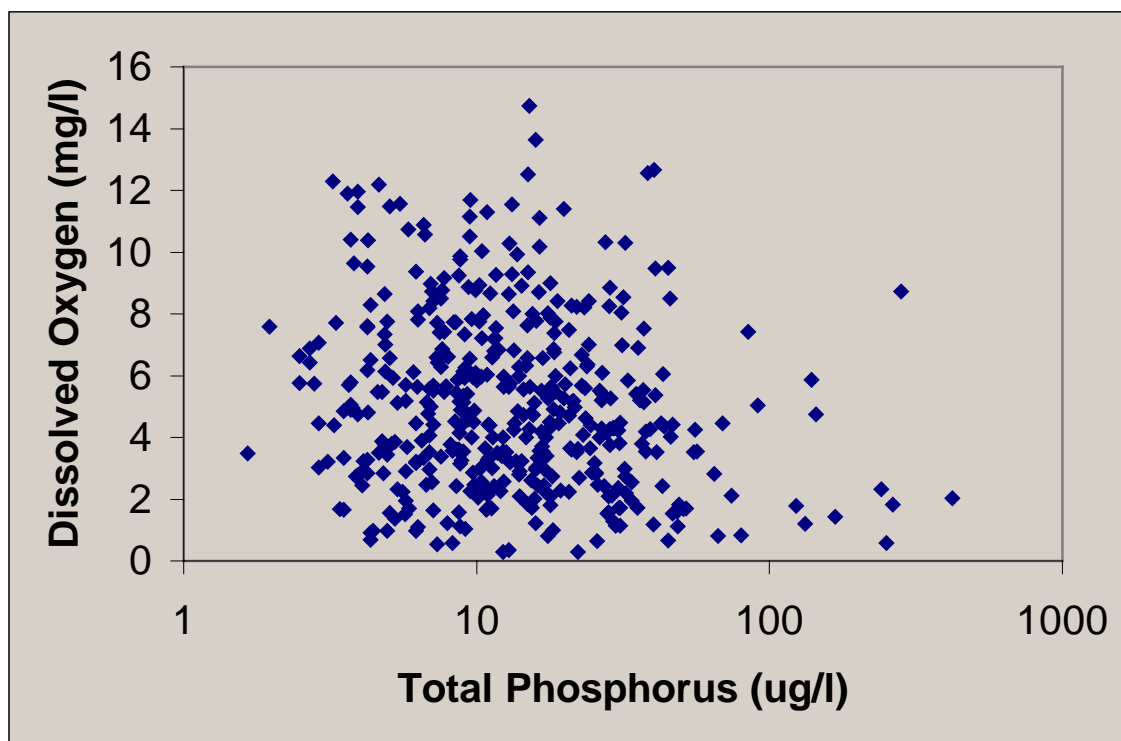
- Any evidence to support the position that eutrophication results in reduction in dissolved oxygen and a concomitant increase in methylmercury concentrations in water
- Testable data, presented in either peer-reviewed publications or as part of the actual report, in preference to reliance on hearsay presented as personal communications
- A discussion outlining the expected impacts of reduced cattail colonization on methylmercury bioaccumulation and the result of the District's efforts to reduce phosphorus concentrations in the water column
- A mercury flux model, relative to biodilution, that examines the overall productivity of eutrophic versus oligotrophic regions, not biased subcomponents
- Evidence that the relationship between *Typha* growth and light permeation is consistent throughout the entire year and not limited to just a few months out of the year
- Evidence to the effect that Everglades macrophytes do not selectively accumulate methylmercury over ionic mercury
- The data upon which Table 7-1 is based

- The quantitative consideration of methylmercury demethylation rates in the District's mercury bioaccumulation and flux models
- A description of the methods applied in probabilistic risk assessment analysis that is consistent with EPA guidance
- The results of goodness-of-fit testing on all distributions used in the probabilistic risk assessment models
- Correction of the probabilistic model to remove the necessity to restandardize the proportional dietary intakes of the receptors
- Quantitative analysis of independence for all variables in the probabilistic risk models
- Second-order Monte Carlo analysis to determine the confidence interval for the prescribed risk estimates
- Justification of the District's definition of "acceptable risk" based on sound metapopulation analysis of the indigenous bird populations
- Proper hypothesis testing and statistical analysis to prove that mercury concentrations in fish, egret feathers, and egret eggs are truly declining with time
- Details on the design of pharmacokinetic models that the District will use to determine the impact of its activities on the Florida panther, Everglades mink, and river otter.

Exponent looks forward to reviewing the District's 2001 Everglades report.

## References

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- Grimshaw, H.J., R.G. Wetzel, M. Brandenburg, K. Segerblom, L.J. Wenkert, G.A. Marsh, W. Charnetzky, J.E. Haky, and C. Carraher. 1997. Shading of periphyton communities by wetland emergent macrophytes: decoupling of algal photosynthesis from microbial nutrient retention. Arch. Hydrobiol. 139:17–27.
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- Lange, T.R., H.E. Royals, and L.L. Connor. 1993. Influence of water chemistry on mercury concentration in largemouth bass from Florida lakes. Trans. Amer. Fish. Soc. 122:74–84.
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**Attachment 1: The relation between total dissolved oxygen and total phosphorus in water at WCA-2A based on EPA's EMAP database. Regression analysis indicates no correlation at  $P = 0.05$ .**



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June 29, 2000

Dr. Garth Redfield  
Lead Environmental Scientist  
Water Resources Evaluation Department  
South Florida Water Management District  
3301 Gun Club Road  
West Palm Beach, FL 33416-4680

Subject: Comments on Chapter 7 of the Everglades Consolidated Report for 2001  
Project No. 8600663.001

Dear Dr. Redfield:

I am writing to summarize the comments and information that Exponent has contributed on behalf of the Sugar Cane Growers Cooperative of Florida to the public record during the review of Chapter 7 of the Everglades Consolidated Report prepared by the South Florida Water Management District (District) and to add some additional information presented by Exponent at the annual all-investigators meeting of the south Florida mercury science program held in Tampa, Florida May 7-11, 2000.

Since the September 30, 1999 public hearing on the 2000 Everglades Consolidated Report, Exponent has provided additional information and comments regarding the ecological risks that mercury poses to wading birds in the Everglades and the inverse relationship between phosphorus concentrations in water and mercury concentrations in fish tissue. The submittals have been as follows:

1. Following the meeting, I posted a comment on the web board on October 1, 1999, to clarify Exponent's opinion that the District had underestimated the risk of mercury toxicity to wading birds in WCA2A.
2. Exponent submitted a technical memorandum on October 19, 1999, containing comments on Chapter 7 of the 2000 Everglades Consolidated Report. The comments related to the District's characterization of the role of phosphorus in mercury bioaccumulation and the District's characterization of ecological risk of mercury to wildlife.
3. Exponent submitted a technical memorandum on March 28, 2000, in response to the invitation from the District to recommend improvements that

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Dr. Garth Redfield  
June 29, 2000  
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could be made in the 2001 report. Exponent provided recommendations on six topics on which improvements to Chapter 7 should be made. The topics include the following:

- Water column phosphorus concentrations
- Mercury flux models
- Relationship of mercury to sulfur cycling
- Probabilistic risk assessment
- Historical trends of mercury concentrations
- Selection of sensitive ecological receptors

Most recently, Exponent made a presentation at the annual south Florida mercury science program held in Tampa Florida May 7-11, 2000. The meeting was hosted by the Florida Department of Environmental Protection (DEP) and brought together investigators funded by DEP and U.S. Environmental Protection Agency and others to discuss issues related to mercury in the Everglades. Dr. Chris Mackay, of Exponent, presented *An Evaluation of Population Risks to Avian and Mammalian Wildlife in the Northern Everglades*. A copy of the graphics used in the presentation is attached.

There are two key themes in our comments mentioned above that merit repeating in this letter. The first theme is that we believe, and continue to find more evidence, that there is definite inverse relationship between phosphorus concentrations in water and mercury in fish tissue. The relationship is the result of the role of phosphorus in eutrophication and is present in the Everglades where total phosphorus exceeds approximately 30 ppb. The second theme is that the District has underestimated the risk of mercury toxicity to wildlife in the Everglades and has ignored the increased ecological risk that will result by reduction of phosphorus concentrations below approximately 30 ppb in WCA2A and elsewhere in the Everglades.

We appreciate the opportunity to review and comment on the District's mercury-related studies. We trust that you have copies of the previous submittals and will consider them along with the attached presentation in preparation of the 2001 Everglades Consolidated Report. Also, we would be pleased to discuss any of these issues with you, at your convenience. Please let me know if you have any questions regarding this letter or if we can supply additional copies of our previous submittals.

Sincerely,

Gary N. Bigham  
Exponent

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Dr. Garth Redfield  
June 29, 2000  
Page 3

cc: Mr. Bill Green, Hopping, Green, Sams & Smith  
Dr. Tom Atkeson, Florida DEP

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Ex



August 18, 2000

Dr. Garth Redfield  
Lead Environmental Scientist  
Water Resources Evaluation Department  
South Florida Water Management District  
3301 Gun Club Road  
West Palm Beach, FL 33416-4680

Subject: Explanation of May 11, 2000 Presentation Graphics  
Project 8600663.001

Dear Dr. Redfield:

On June 29, 2000 I sent, on behalf of the Sugar Cane Growers Cooperative of Florida, a copy of the graphics Dr. Chris Mackay of Exponent presented at the annual south Florida mercury science program held in Tampa Florida May 7-11, 2000. Today I am transmitting, for your consideration, an expanded version of the same presentation, *Evaluation of Population Risks to Avian and Mammalian Wildlife in the Northern Everglades*. This version includes the same presentation graphics (Appendix B) but provides a clarifying discussion of the background, methodology, and results.

We appreciate the opportunity to comment on the District's mercury-related studies. We trust that you will consider them in preparation of the 2001 Everglades Consolidated Report. I have also provided copies to Dr. Tom Atkeson at the Florida Department of Environmental Protection. Please let me know if you have any questions regarding this submittal.

Sincerely,

Gary N. Bigham  
Exponent

cc: Mr. Bill Green, Hopping, Green, Sams & Smith  
Dr. Tom Atkeson, Florida DEP

## **Technical Memorandum**

### **Evaluation of Population Risks to Avian and Mammalian Wildlife in the Northern Everglades**

Prepared for

Sugar Cane Growers Cooperative of Florida  
1500 West Sugarhouse Road  
Belle Glade, Florida 33430

Prepared by

Exponent  
15375 SE 30th Place, Suite 250  
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August 2000

## Evaluation of Population Risks to Avian and Mammalian Wildlife in the Northern Everglades

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### Abstract

Piscivorous wildlife in the Everglades may be exposed to toxic levels of mercury because of elevated concentrations in fish. An analysis of the risk due to mercury exposure for three piscivorous Everglades species, the wood stork, the blue heron, and the Everglades mink, is presented in this paper. Using data from two sites in the Everglades, one associated with low phosphorus in water (<10 ppb), and the other associated with relatively higher concentrations (>10 ppb), we show that a greater proportion of the populations of all three receptors are at risk of exposure to toxic levels of mercury in zones with low phosphorus compared to high phosphorus zones. Restoration efforts currently in progress in the Everglades seek to reduce the inflowing phosphorus concentrations to an interim target of 50 ppb, with further reductions being planned. This study clearly shows in zones that now contain higher levels of phosphorus, the reduction of concentrations to levels much lower than 50 ppb will have the unintended consequence of increasing mercury risk to higher trophic level organisms. Therefore, in assessing the benefits of phosphorus reduction to very low levels, consideration must also be given to the likely increase of mercury risks when phosphorus concentrations are reduced below 50 ppb.

### Introduction

Dr. Chris Mackay of Exponent gave a presentation titled *An Evaluation of Population Risks to Avian and Mammalian Wildlife in the Northern Everglades* to the all investigators meeting of the South Florida Mercury Science Program (Tampa, Florida, May 7–11, 2000). This paper presents the graphics included in the presentation (Appendix B) and provides an explanation of the background, methodology, and results.

### Background

The regions of the Florida Everglades north of Everglades National Park have been of particular ecological concern with regard to disturbance introduced by humans. A primary concern has been the potential impact of the phosphorus in stormwater discharges on the eutrophication of the Everglades. As a result of this concern, a restoration effort is currently underway that seeks to reduce the concentrations of phosphorus in discharged water to an interim value of 50 ppb by constructing approximately 50 square miles of treatment wetlands (termed Stormwater Treatment Areas or STAs). Water from the STAs will be discharged in some nutrient enriched areas and in some unenriched areas (details of the STA layout can be found in SFWMD 1999). A second phase of this restoration effort has the objective of further lowering this phosphorus standard to a level that would not cause an imbalance in populations of flora and fauna in the most oligotrophic areas of the Everglades. Toward this end, research efforts are in progress to understand the response of the Everglades ecosystem to phosphorus additions. The Florida Department of Environmental Protection has preliminarily suggested that such areas should not receive water containing more than 10 ppb of phosphorus (FDEP 1999).

Another threat to wildlife in the Florida Everglades is unusually high concentrations of mercury in indigenous fishes. Most mercury enters the Everglades through atmospheric deposition, and not through surface water flow. The sources of atmospheric mercury, and the relative influences of local and global sources, are a subject of active research. Concentrations of mercury in fish have been observed to exceed the FDA action level of 1 mg/kg.

Accumulations of mercury to such high concentrations may represent a significant toxicological hazard to indigenous wildlife that rely on fish from the Everglades as their primary source of food.

Mercury concentrations in fish and water column concentrations of phosphorus appear to have an inverse relationship in much of the Everglades. Areas that now have relatively high levels of phosphorus also have the lowest concentrations of mercury in fish. Areas in the interior and the southern part of the Everglades, where phosphorus concentrations are at background levels, generally lower than 10 ppb, have some of the highest measured concentrations of mercury in fish in the United States. In other words, areas in the Everglades that are unenriched by phosphorus are enriched by mercury. This finding has important ramifications for the phosphorus restoration plans in the Everglades. Should the STA discharge concentration be in the vicinity of 50 ppb, the currently nutrient-enriched areas receiving this water will continue to have low concentrations of fish mercury, and currently unenriched areas will have lower fish mercury than at present. Should the STA discharge concentrations be 10 ppb or lower, these benefits will not be realized.

The inverse relationship between water column phosphorus concentrations and fish mercury concentrations can be explained by the process of biodilution. Biodilution is a phenomenon observed in numerous water bodies including the Florida Everglades. In essence, it is an inverse relation between the mass of primary producers and the concentration of mercury in the biomass. Because the influx of mercury is from the atmosphere, and independent of biomass, in the presence of high biomass, the mercury is taken up by a larger number of primary producer organisms, thereby lowering the concentration in individual organisms. Conversely, in low-biomass areas, the same amount of mercury is taken up by a smaller number of organisms with higher individual concentrations. The concentration of mercury in primary producers is important because it is the base of the Everglades aquatic food web. Mercury, specifically methylmercury, adsorbed to primary producers such as algae in periphyton or in the benthos is consumed by predators that are eventually consumed by fish. At each successive step in the food chain, mercury biomagnifies to higher and higher concentrations (U.S. EPA 1997b), often being a million times higher in fish tissue than in water. This inverse relationship between eutrophication and mercury bioaccumulation was first described by D'Itri et al. (1971). A similar inverse relationship has been reported with polychlorinated biphenyls (PCBs), another class of biomagnifying compounds, in plankton in 33 Canadian lakes (Taylor et al. 1991) and with PCBs in fish in 61 Scandinavian lakes (Larsson et al. 1992). Exponent (1998) summarizes much of the recent literature reporting observations of the inverse relationship between eutrophication and mercury in fish in the Everglades and other systems.

Other processes, also related to high primary production, such as formation of mercury sulfide and polysulfide species in sediment pore water also act to reduce mercury methylation (Benoit et al. 1999) and bioaccumulation. The net effect of these phosphorus-related processes is clearly seen today in the north-to-south gradient of decreasing phosphorus concentrations in the water of WCA-2A and the corresponding gradient of increasing mercury concentration in fishes (Exponent 1998; SFWMD 1999). It is also evident in Lake Okeechobee where phosphorus concentrations are similar to the enriched area in WCA-2A and mercury concentrations in fish do not exceed 1 mg/kg.

Given the demonstrable relation between phosphorus concentrations in the water column and mercury concentrations in the fishes, there is a serious potential that efforts to reduce phosphorus concentrations in the northern Everglades will have the unintended consequence of increasing wildlife exposures to mercury. Because of the inverse relation described above, areas that now contain high levels of phosphorus, such as the northern part of WCA-2A, have low concentrations of mercury in the fish. As a result of the construction of the STAs, these areas in the northern Everglades will receive water at approximately 50 ppb of phosphorus or lower. With influent water at these concentrations, these areas of the northern Everglades can be thought of as "safe zones" with respect to mercury for higher trophic level organisms. If the phosphorus concentrations in these areas are reduced to very low levels (i.e., to levels in the vicinity of 10 ppb) by means of technologies supplemental to the STAs, it is likely that the effects the areas have in reducing mercury bioaccumulation will be lost. These zones will have higher mercury concentrations in fish, and will lose their function as safe zones for mercury.

The South Florida Water Management District (SFWMD), as required by the EFA, has performed annual evaluations of environmental conditions, including the distribution of mercury and its toxicity, within the Everglades (SFWMD 1999, 2000). These reports also include qualitative considerations of mercury risks resulting from reductions in phosphorus inputs. The SFWMD has attempted to assess the risks of mercury toxicity to Everglades

wildlife by assessing the current risks to piscivorous wading birds in the low phosphorus regions of WCA-2A and in WCA-3A. Their risk analyses have consistently shown that a significant proportion of the indigenous wading bird populations, including the threatened wood stork, would be exposed to levels of mercury sufficient to produce adverse toxicological effects in a significant portion of the indigenous populations. Some analyses have shown impacts in up to 50 percent of the bird populations (SFWMD 1999, 2000). In spite of these results, the SFWMD concludes that phosphorus reduction will not increase mercury exposure and current risks to wading birds even though they have never specifically evaluated the risk posed by mercury in the nutrient-enriched areas, nor attempted to compare this to mercury risk demonstrated in the non-nutrient-enriched areas of the Everglades.

This study examines risks from mercury exposure using a conceptual model not considered by the SFWMD. A comparative ecological risk assessment was performed in this study to contrast the potential threat associated with exposure to mercury in areas known to have high water column phosphorus concentrations (i.e., contain concentrations of phosphorus greater than 10 ppb), versus those known to have lower water column phosphorus concentrations. The risk assessment was performed using indigenous ecological receptors that rely on fish taken from the Florida Everglades as their primary source of food.

## Problem Formulation and Approach

The problem formulation phase of the risk assessment involved the identification of the areas under consideration for assessment, the receptor for which the risk will be characterized, and the identification and analysis of the stressor. Because the purpose of this assessment is to determine the effects of water column phosphorus concentrations on mercury risk, two areas were defined on this basis. The phosphorus-enriched area was defined as any region within WCA-2A where water column phosphorus concentrations exceeded 10 ppb. The unenriched area was defined as any region within WCA-2A where water column phosphorus concentrations are known to be less than 10 ppb. The receptors of concern were sentinel top predators that are indigenous to WCA-2A and consume primarily fish. The stressor of concern is methylmercury. The route of exposure was limited to the ingestion of fish since this is by far the largest and the only significant source of mercury exposure for the top predator receptors.

The receptors for risk characterization were selected based upon their presence within the northern Everglades, their foraging behaviors relative to potentially contaminated fish, and their social value. Specific species were as follows:

- **Great blue heron**—The great blue heron (*Ardea herodias*) is a wading bird indigenous to the Florida Everglades and is a year round resident. It is one of the largest of the wading birds and catches its prey by stalking fish in shallow, clear water. Because it tends to eat larger prey that accumulate higher mercury concentrations, it was deemed to be the wading bird at highest risk.
- **Wood Stork**—The wood stork (*Mycteria americana*), like a great blue heron, is one of the larger of the wading bird species. However, its foraging technique, which involves tactile probing, results in a diet composed of comparatively smaller fish. The wood stork was retained for assessment because it is considered to be a threatened species under both state and federal law and therefore possesses inherent social value.
- **Everglades Mink**—The Everglades mink (*Mustela vison evergladesis*) is a subspecies of mink and is indigenous to the Florida Everglades. It eats predominantly fish and is listed by the state of Florida as a threatened species. Therefore the mink was considered for risk characterization as both a sentinel piscivorous mammal as well as for its inherent social value.

The stressor of concern in this assessment was exclusively methylmercury. Methylmercury is the only species of mercury that has been demonstrated to significantly bioaccumulate within aquatic organisms. Typically, methylmercury will constitute greater than 95 percent of the mercury concentration within prey fishes. Furthermore, methylmercury is highly toxic with chronic acute toxic dosages much lower than any of the inorganic mercury species. Therefore, methylmercury represents the greatest risk to piscivorous wildlife. Furthermore, because the

potential effect of phosphorus reduction in the enriched area, it is possible that significant reductions of phosphorus loadings to the Everglades will increase the mercury concentrations in Everglades fish and therefore elevate the risk of impact to the above listed receptors.

## Probabilistic Assessment

The risk assessment was performed on a probabilistic basis. Therefore, the risk characterization was expressed as a probability density function (i.e., a relation that expresses a given measured parameter, such as risk, in terms of the probable likelihood that it will occur), specifically as the proportion of the population that exceeded the threshold toxicity. This method uses the same paradigm as that applied in determinant hazard quotient methodologies developed by EPA (U.S. EPA 1997a) and can be expressed as follows:

$$\text{Risk} = \frac{\text{exposure}}{\text{response}}$$

In the application of this paradigm in a probabilistic analysis, probability density functions are substituted for the variables (denoted as  $f(x)$ ) thus treating them as functions rather than as determinant values as follows.

$$f(\text{Risk}) = \frac{f(\text{Exposure})}{f(\text{Response})}$$

$$\bar{f}(r) = \frac{(9.66 \times \log(\bar{f}(\text{BW}))^{-0.64}) \times \bar{f}([\text{Hg}]) \times f(F)}{\text{TRV}} \left( \frac{d\text{BW}}{dP} \right) \left( \frac{d[\text{Hg}]}{dP} \right) \left( \frac{dF}{dP} \right) \left( \frac{d\text{TRV}}{dP} \right)$$

Model derivation and function definitions are detailed below and in Appendix A.

As a result of this approach, the risk characterization ( $f(r)$ ) will also be a probability density function expressed as the ratio of exposure concentrations to the toxicity reference value (TRV) in terms of likelihood of a particular ratio occurring within the population of all receptors exposed. The TRV, by definition, represents the threshold exposure rate below which no adverse toxicological response would be expected.

The parameters used in the risk model are listed in Table 1. Particulars on the derivation of probability density functions used as inputs for this assessment were as follows:

**Sampling Locations**—The risk characterization used mercury concentrations from fish collected within WCA-2A by the Florida Fish and Wildlife Conservation Commission (FFWCC) and SFWMD. Three sampling sites where a variety of differing species of fish were collected over a broad size range were identified (Figure 1). The first, designated F1, was part of the transect study performed by SFWMD in 1998 (SFWMD 1999). Data from this station were used to characterize the enriched area. For the characterization of the unenriched area, two sites were identified. These were designated as U3 and GH by SFWMD and FFWCC, respectively and identified in SFWMD (1999).

**Receptor Prey Selection**—For the purposes of this assessment, the receptor's diet was assumed to consist of 100 percent fish taken from either area. Prey selection was determined based on literature reports of the receptors fish size and species preference (Table 1). Statistical methods applied in the development of the probability density functions are detailed in Appendix A.

**Dietary Intake Rates**—Species-specific dietary intake rates were determined from the literature. For the wading birds (great blue heron, and wood stork) daily food intake was determined based on the allometric regression developed by Kushlan (1978) as follows:

$$\log(\text{Intake Rate}) = 0.966 \times \log(\text{Body Weight}) - 0.64$$

The intake rate is expressed in kg per kg per day and the body weight of the receptor is expressed in kg. The intake rate for the Everglades mink was determined using the allometric regression of Nagy (1987) specific for carnivorous mammals as follows:

$$\log(\text{Intake Rate}) = 0.0687 \times \log(\text{Body Weight}) + 0.822$$

Distribution of body weight's for each of the receptors was collected from the literature and selected as the best available to be representative of population's indigenous to the Florida Everglades (see Table 1).

**Toxicity Reference Value (TRV)**—Risk equations are extremely sensitive to the estimate of threshold toxicity. Unfortunately, the present understanding of mercury toxicity, particularly in birds, is insufficient to develop a probability density function (i.e., dose/ response curves). Therefore, the threshold toxicity was assumed to be a single value and any proportion of the population whose intake rate exceeded that value would be deemed to be exposed to an unacceptable risk.

The TRV used in this assessment for the piscivorous birds was derived from a study by Heinz (1979) that evaluated reproductive effects of methylmercury ingestion in mallards over three generations. From the study, it was determined that the lowest dose that showed an effect was 0.064 mg/kg-day. Using a safety factor of 0.5, to account for uncertainty between lowest effective and the no effect level, a TRV of 0.150 mg/kg-day was determined.

The TRV used in the assessment of the Everglades Mink was based on a feeding study performed by Wobeser et al. (1976). During the 13-week study, mink were exposed to various concentrations of methylmercury introduced in their diets. The lowest concentration of 4.4 mg/kg dry weight produced no overt signs and was therefore considered to be a no effect level. From this concentration a TRV of 0.038 mg/kg-day was determined.

**Probabilistic Risk Model**—Using the above mentioned probabilistic risk model, the functional components of the integral were replaced with the probability density functions described above. The integral was solved by iteration using the Monte Carlo method. The resulting risk function was then expressed as a probability density function of the ratio of exposure rates to the threshold TRV.

## Risk Characterization

The probability density functions for the risk to the three receptors considered are illustrated in Figures 2 through 4. In all cases, the receptor populations were exposed to higher concentrations of mercury in the unenriched area compared to populations in the enriched area. The relative differences varied with species. Statistical descriptors of the probability density functions are provided in Table 2. The coefficients of variability were consistently higher in the unenriched area. This is surprising since the number of fish observations for this area was  $n = 200$ , as compared to only  $n = 35$  for the high phosphorus assessment unit. If the samples were representative of the variability in mercury concentrations within this region, then one would expect the coefficient of variability to decline as the number of sampled individuals increases. This indicates that there is significantly higher variability, likely the result of higher overall mercury concentrations, in the unenriched area compared to the enriched area.

The proportional percentages of the populations determined to be at risk (i.e., exposure rates exceeded the TRV) are listed in Table 3. For all receptors considered in this risk characterization, the risk associated with the exposure to mercury was higher in the unenriched area compared to the enriched area. In the cases of the great blue heron and

the Everglades mink, projected impacts within the enriched area approached 60 percent of the population as opposed to 15.5 and 33.4 percent, respectively, within the enriched area. For the wood stork, the hazard associated with the unenriched area was 15.4 percent of the population at risk compared to only 3.1 percent in the enriched area. Although lower proportions of risk were observed for this species, it must be noted that the wood stork is a state and federally designated threatened species and thus is afforded a higher level of protection. Therefore, the distribution of mercury contamination in fish, relative to the prey selection of the three receptors, would result in increased risk of adverse impacts anywhere from two to five times within the unenriched area compared with the enriched area.

## Uncertainty Analysis and Data Gaps

Uncertainty in the above estimates can be divided into four basic sources. First, there is error associated with the characterization of the region based on available sampling. Second, there is error associated with the assumptions made on the behavior of the receptors in order to estimate their potential exposures. Third, there is error associated with the assumptions of toxicological response. Fourth, there is error associated with the application of the integral model to WCA-2A.

In most risk assessments, uncertainty associated with site characterization is the easiest to control. This is because site characterization is usually performed *a priori* to the risk assessment and designed specifically to fulfill its requirements. This was not the case in this situation. The data available for application in this risk assessment were originally attained to fulfill other risk assessment requirements of the SFWMD. The SFWMD has to date neglected to consider how the reductions in phosphorus concentrations in the enriched area will affect the risk due to mercury exposure within those regions. Therefore, the data had to be adapted from alternative conceptual models and cannot be considered as optimum. However, analyses of uncertainty indicate that the variation between the two proportional risk estimates was predominantly based on lower mercury concentrations in the fish found in the enriched area, compared to the unenriched area of the Everglades and that within the uncertainty of the risk characterization, was statistically significant.

Predictions of receptor behavior were based on the best available information from the current scientific literature. Where possible, site-specific or Everglades-specific information was applied in the receptor's characterization. However, local variations, particularly with regards to availability of prey size cohorts and the distribution in fish species present may have introduced unpredictable uncertainty into the risk characterization particularly with regards to absolute quantification. However, assumptions were held constant between both the enriched and unenriched areas and thus the relative uncertainty between the two regions should have been minimized with regards to estimated errors in receptor behavior.

The greatest potential source of error in the risk characterization was associated with the selection of the TRV. Because this is the sole factor in the denominator of the risk function, the estimations of risk are highly sensitive to variations in this value. Furthermore, the prediction of response based on a single value inherently ignores biological variation both between species and within receptor populations. Therefore, to ensure that any error associated with the TRV selection results in an overestimation of risk rather than an unanticipated underestimation, the TRV selected is the most reasonably conservative available and has been adopted by the U.S. EPA for mercury-specific risk assessments associated with the Great Lakes water quality initiative (U.S. EPA 1995) as well as the mercury report to congress (U.S. EPA 1997b).

The most difficult source of uncertainty to estimate is that associated with model error. Model error describes the variance between the dynamics of the situation (i.e., conditions in WCA-2A) and those predicted by the relations within the functional model. For example, the paradigm commonly used in ecological risk assessment assumes a static situation where a receptor is consistently exposed to a given situation for a period of time. It also assumes the conditions are in steady state both with regards to defined locations as well as with regards to temporal considerations. This is known not to be the case. Therefore to control for this type of uncertainty, the risk paradigm has been established to model a "worst-case population" and as such, any potential derivation from the risk model would result in a mediation of potential impact.

## Conclusions

In order to determine the impact of proposed phosphorus reductions, it would be most reasonable to examine the changes in risk within those areas that are to be most affected. It is for this reason that this study compared the relative risk between high and low phosphorus regions within WCA-2A. The underlying assumption in this case is that as phosphorus concentrations decline within the enriched area, the risk due to exposure to mercury will approach levels consistent with that observed in the unenriched area. If this is so, then the risk from exposure to mercury can be expected to increase between 2 and 5 fold within the enriched area. Furthermore, this change in risk is primarily the result of increases in mercury fish concentrations taken from either high or low water column phosphorus regions of the Florida Everglades. Therefore, reductions in phosphorus concentrations in runoff in the northern Everglades, will result in the undesirable consequence of raising the mercury risk to key threatened bird and mammal species.

One possible mechanism for increases in mercury concentrations within prey fish with declines in phosphorus concentration in the water column is the result of changes in biodilution and other processes related to eutrophication. If, as part of the restoration efforts in the northern Everglades, phosphorus discharge concentrations are reduced to levels approaching 10 ppb, the productivity and therefore the overall biomass will also fall. This will result in the accumulation of mercury at higher concentrations within the remaining biomass and thus increase the rate at which it is introduced into the aquatic food web. In this case, increased mercury risk is certain to be the result of reducing the phosphorus concentrations within the enriched area. If, on the other hand, phosphorus concentrations in water discharged from the STAs are in the vicinity of 50 ppb, areas of the northern Everglades that receive this water will continue to have sufficient levels of productivity to allow for biodilution of mercury in the biomass, and will serve as a safe zone with respect to mercury for higher trophic level organisms.

In earlier work, Tetra Tech (2000) showed the historical presence of a nutrient gradient in the Everglades and the possible benefits to the ecosystem because of the existence of a range of phosphorus concentrations. The benefits include higher productivity, greater peat accretion, and greater abundance and richness of wildlife. A gradient of nutrient concentrations will result if the STAs operate at or near their designed discharge concentration of 50 ppb, but not if the influent concentrations are reduced in the future to near the background concentration of 10 ppb. The analysis of risk presented in this paper shows that, in addition to the benefits outlined in Tetra Tech (2000), the Everglades will benefit from having zones with lower mercury exposure if phosphorus concentrations in the STAs are maintained at or near their currently designed targets.

Because of the uncertainty associated with this analysis, particularly with regards to the limited data available, it is difficult to be certain that the predictions presented are suitably accurate. However, the differences in risk were statistically significant and indicate that, in the light of our understanding of conditions within WCA-2A, there is a potential that phosphorus reduction activities will significantly increase the risk for mercury exposure in both avian and mammalian top predators. Some species included in this guild, specifically the wood stork and the Everglades mink, are recognized at the state and/or federal level as threatened species and therefore afforded special protection under the law. Further investigations of the mercury risk due to phosphorus reductions are warranted in light of this analysis.

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## **Figures**

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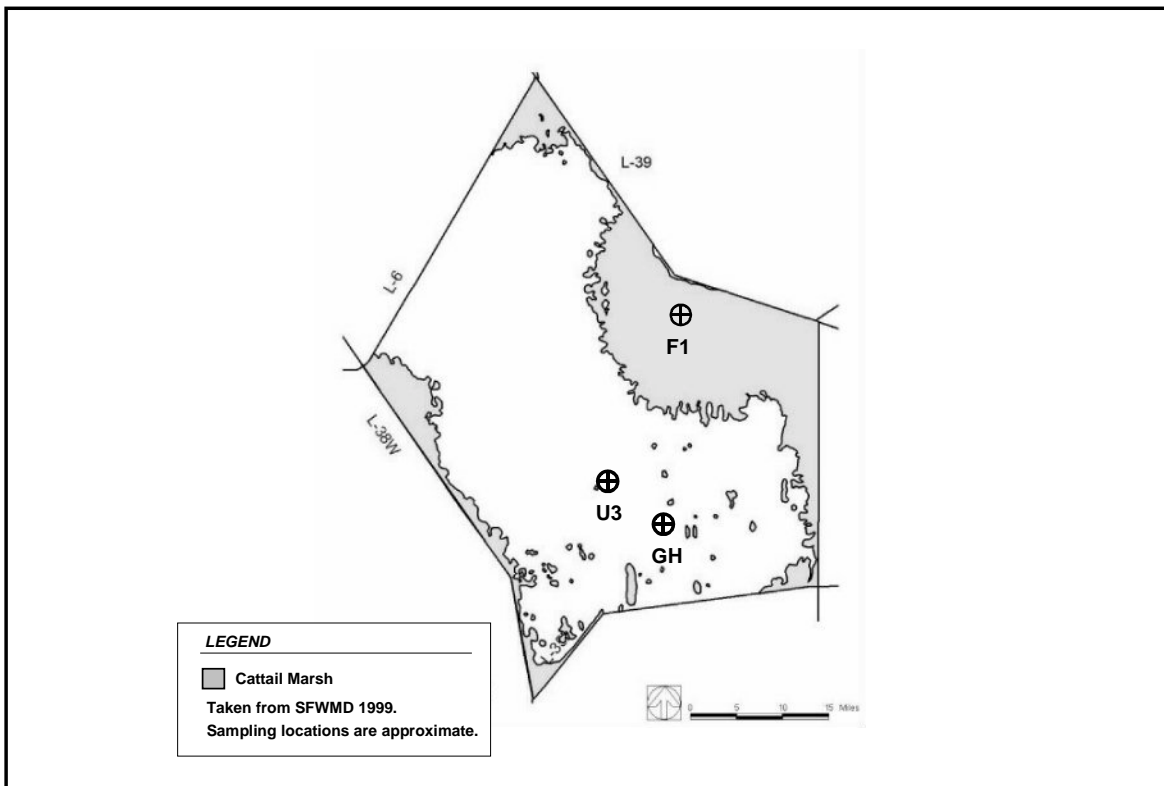


Figure 1. Regional scenarios

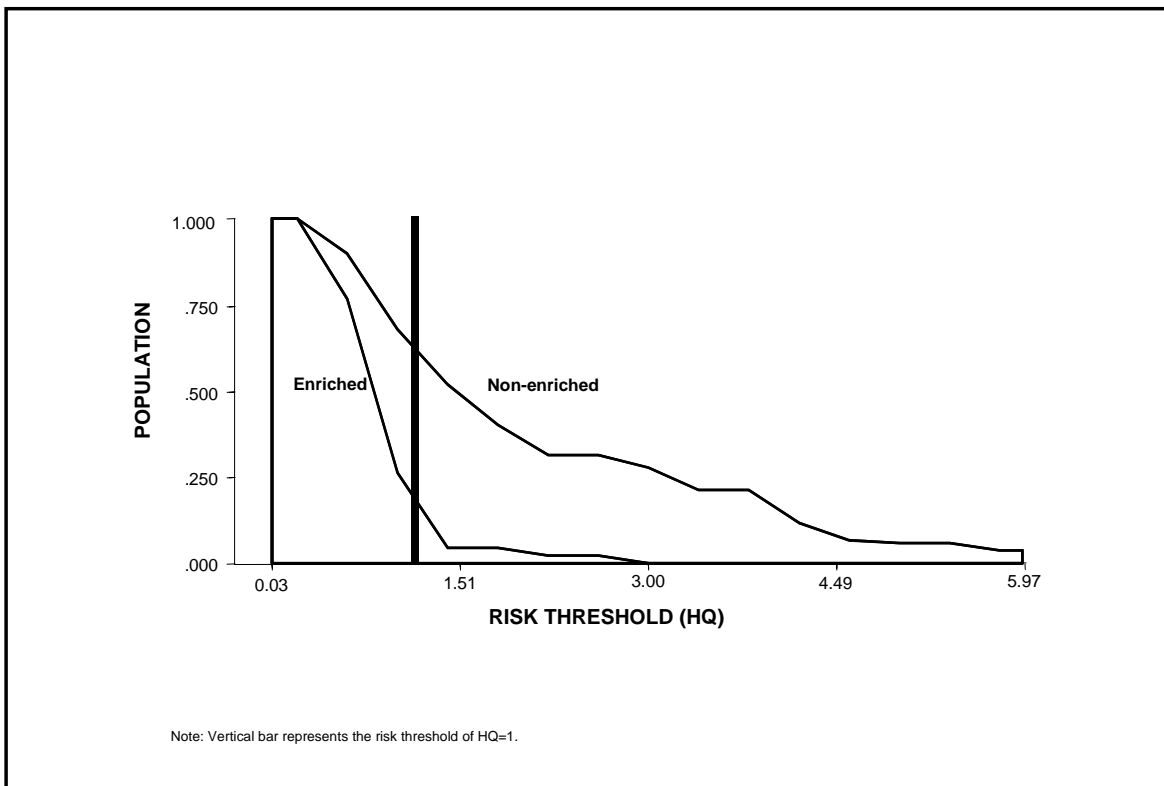


Figure 2. Probability density function of risk from exposure to mercury for the great blue heron

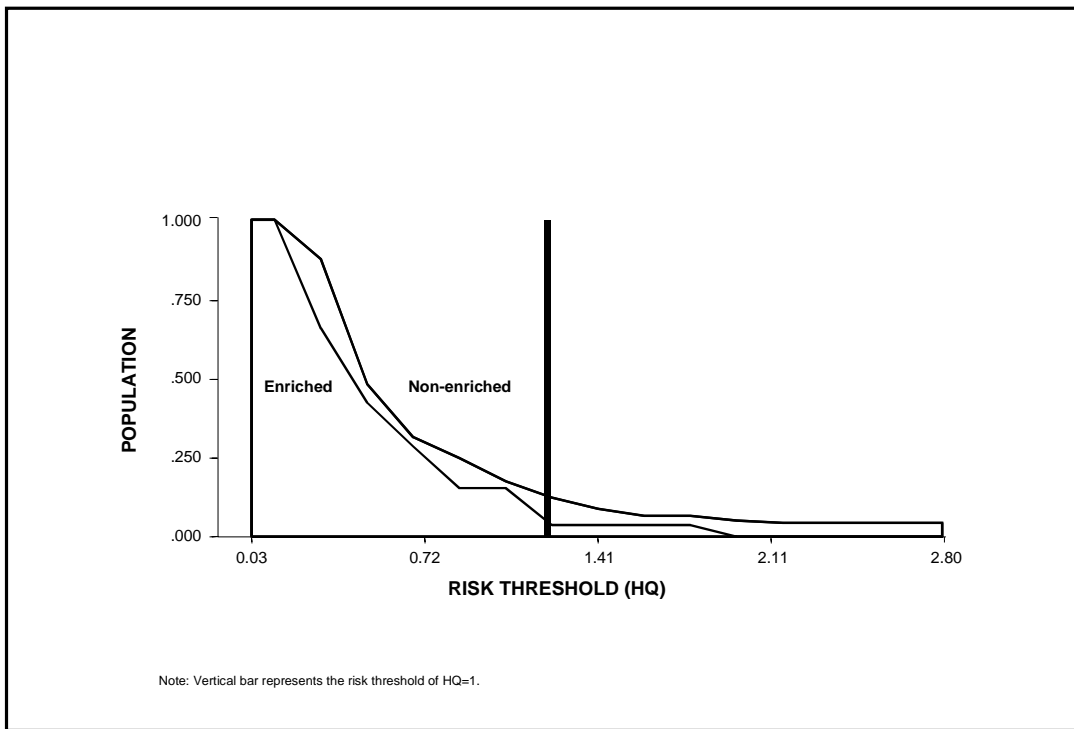


Figure 3. Probability density function of risk from exposure to mercury for the wood stork

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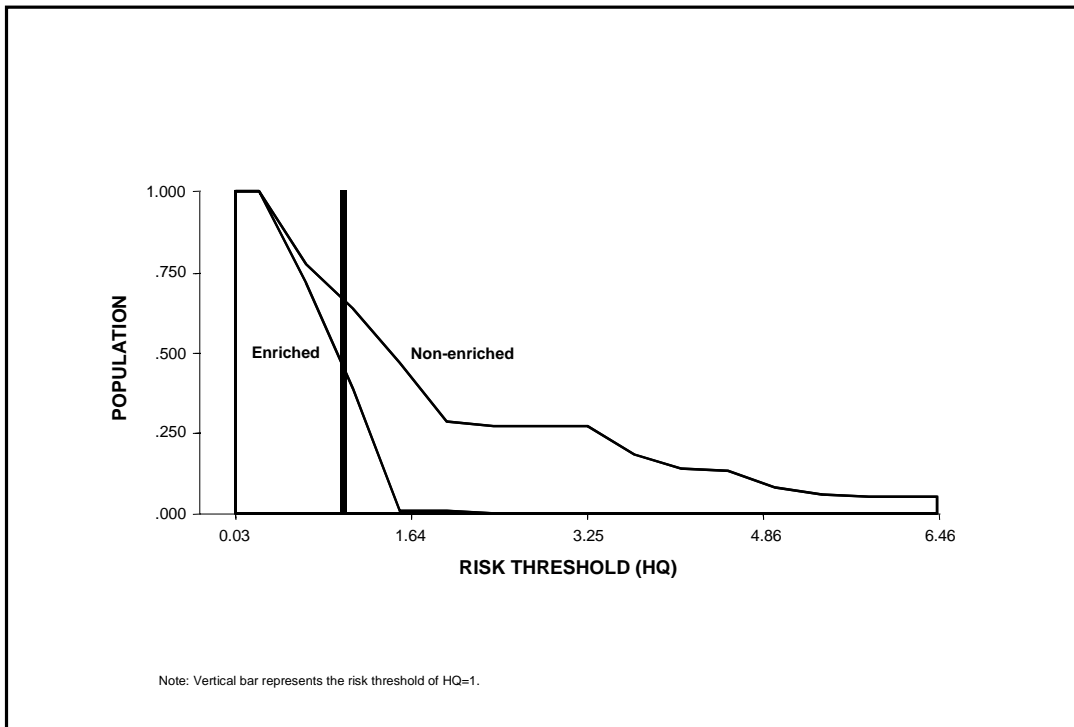


Figure 4. Probability density function of risk from exposure to mercury for the Everglades mink

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## **Tables**

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**Table 1. Input parameters used in the evaluation of receptor risk associated with exposure to mercury**

Parameter/Receptor	Type of Parameter	Value/Distribution	Notes
<b>Great Blue Heron</b>			
Body mass	Normal distribution	$2.2 \pm 0.34$ kg	Based on Dunning (1984)
Intake rate	Distribution	$220 \pm 1.1$ g/kg-day	Using Kushlan (1978) based on body mass distributions
Prey selection	Classed distributions	5–7 mm: 7.90 percent 7–14 mm: 40.3 percent 14–33 mm: 51.8 percent	Based on Alexander (1977)
Enriched area mercury concentrations	Assumption-free distribution	$0.33 \pm 0.39$ mg/kg DW	Based on fish species abundance distributions and receptor prey selection
Unenriched area mercury concentrations	Distribution	$0.12 \pm 0.17$ mg/kg DW	Based on fish species abundance distributions and receptor prey selection
TRV	Value	0.032 mg/kg-d	LOAEL-derived, based on the toxicity of mercury to mallards
<b>Wood Stork</b>			
Body Mass	Distribution	$2.4 \pm 0.35$ kg	SFWMD (2000)
Intake Rate	Lognormal distribution	$220 \pm 1.3$ g/kg-day DW	Using Kushlan (1978) based on body mass distributions
Prey Selection	Classed distributions	6–6.8 mm: 16 percent 6.8–11.7 mm: 44 percent 11.7–15 mm: 39 percent	Based on Ogden et al. (1976)
Enriched area mercury concentrations	Distribution	$0.08 \pm 0.07$ mg/kg DW	Based on fish species abundance distributions and receptor prey selection
Unenriched area mercury concentrations	Distribution	$0.13 \pm 0.17$ mg/kg DW	Based on fish species abundance distributions and receptor prey selection
TRV	Value	0.032 mg/kg-d	LOAEL-derived, based on the toxicity of mercury to mallards
<b>Everglades Mink</b>			
Body mass	Distribution	$646 \pm 33$ g	U.S. EPA (1997a)
Intake rate	Distribution	$297 \pm 0.25$ g/kg-day	
Prey selection	Classed distributions	5–7.6 mm: 11 percent 7.7–10 mm: 29 percent 10.1–15 mm: 48 percent 15.1–18 mm: 12 percent	Based on Alexander (1977)

**Table 1 Cont.**

Enriched area mercury concentrations	Distribution	0.27 ± 0.20 mg/kg DW	Based on fish species abundance distributions and receptor prey selection
Unenriched area mercury concentrations	Distribution	0.11 ± 0.06 mg/kg DW	Based on fish species abundance distributions and receptor prey selection
TRV	Value	0.15 mg/kg-d	NOAEL-derived, based on the toxicity of mercury to mink

**Note:** LOAEL - lowest-observed-adverse-effect level  
NOAEL - no-observed-adverse-effect level

**Table 2. Statistical analysis of probability density function describing risk due to exposure to mercury for the three wildlife receptors modeled**

Receptor/Region	Median	Variance	Skew	Kurtosis	Coefficient of Variability
<b>Great Blue Heron</b>					
Enriched	0.63	0.18	2.01	10.31	0.63
Unenriched	1.91	2.56	1.13	3.4	0.84
<b>Wood Stork</b>					
Enriched	0.38	0.13	1.49	5.63	0.8
Unenriched	0.70	0.79	3.64	18.75	1.27
<b>Everglades Mink</b>					
Enriched	0.78	0.16	-0.12	2.61	0.54
Unenriched	1.78	3.16	1.35	4.19	1.00

**Table 3. Estimates of the proportions populations at risk from exposure to mercury in the high and unenriched areas of WCA-2A**

Receptor	Percent Population At Risk	
	Enriched Areas	Unenriched Areas
Great blue heron	15.49	59.12
Wood stork	3.05	15.42
Everglades mink	33.42	57.52

## **Appendix A**

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### **Quantitative Methods for Probabilistic Risk Assessment in the Florida Everglades**

## Quantitative Methods for Probabilistic Risk Assessment in the Florida Everglades

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### Introduction

Ecological risk assessment is based on the comparison of rates of exposure to estimates of a dose associated with a toxicological response. The standard paradigm for this comparison is a comparative ratio of exposure rates over threshold doses:

$$r = \frac{e}{t}$$

where risk (r) is defined as a numerical, unitless, measure of the magnitude of difference between exposure (e) and response (t). The magnitude of this value has no applicable biological relevance with the exception of whether the value is greater than or less than one. A value greater than 1 indicates that the exposure has exceeded the threshold response and that there is a risk that the response ascribed to t will occur. A value of r less than 1 indicates that the exposure rate is not sufficient to induce such a result and therefore there is no risk of the response ascribed to t occurring.

In the risk assessment presented in this paper, the receptor's exposure is dependent upon the mercury concentration in fish ([Hg]) and the daily rate at which the receptor eats fish (IR). The response is characterized by a response threshold (t) which represents a safe mercury dose that can be expected to produce no adverse toxicological effects. In essence, the underlying assumption in the risk paradigm is that if the receptor's rate of exposure is less than the response threshold, then there is no risk of an adverse impact. Using these exposure and effects parameters, the risk paradigm may be expressed as follows:

$$r = \frac{IR \times [Hg]}{t}$$

Another method to describe risk, using the same paradigm, is to examine the probability (or proportion of the population) likely to exceed a ratio of 1. To do this, it is necessary to describe the distribution of the population of all individuals potentially at risk. Such descriptions are called probability density functions (denoted as f(x)). In essence, the probability density function is a relation where the value of a specific variable (mercury concentration, body weight, intake rate, etc.) is expressed in terms of the proportion of a defined population likely to be represented by that value.

In probabilistic ecological risk assessment, values intended to describe ecotoxicological aspects necessary for the estimation of either exposure or risk are replaced with probability density functions. Therefore the risk paradigm can be expressed as follows:

$$\bar{f}(r) = \frac{\bar{f}(IR) \times \bar{f}([Hg])}{\bar{f}(t)} \left( \frac{dIR}{dP} \right) \left( \frac{d[Hg]}{dP} \right) \left( \frac{dTRV}{dP} \right)$$

Because the model must now describe not a single value, but rather a range of values based on the probability distribution inputs, it must be considered as a probability dependent (dP) integral where the risk will be defined from a probability of 0 to 100 percent.

There is one important assumption underlying the solution of a probabilistic risk model. The probability functions must be independent. If the functions are at all dependent either on each other, or a common state variable, so that the probability of one event occurring will change based on the probability of another modeled event, then the mathematical solution may be highly invalid relative to the actual situation.

In most cases, it is impossible to derive a mathematical relation that describes the probability density functions and therefore directly solve the integral. In most situations, these functions are based on empirical observations with a structure that cannot be expressed mathematically. There are cases where statistical relations may be inferred with regards to the behavior of the distribution relative to probability (i.e., normal, lognormal, triangular). It should be noted that the use of such distributions requires an inference of a mathematical relation independent of factors governing the probability distributions and therefore could be a significant source of error. Such inferences should only be used when insufficient empirical data are available to develop assumption-free distributions. When such data are available, the probability density functions should be based on the actual observed frequencies. Methods for developing such distributions are detailed in Fishman (1996).

The substitution of a probabilistic density function into the risk paradigm permits the opportunity to consider other potential affecting factors on either exposure or response. For example, it is known that in the Florida Everglades mercury concentration increases with the size of fish. Therefore, the probability of exposure to a given mercury concentration may be expressed as the probability of the mercury coming from a fish of a given size (S). Therefore, the risk model may be modified as follows:

$$\bar{f}(r) = \frac{\bar{f}(IR) \times \bar{f}([Hg]|S)}{\bar{f}(t)} \left( \frac{dIR}{dP} \right) \left( \frac{d[Hg]}{dP} \right) \left( \frac{dTRV}{dP} \right)$$

In this situation, the mercury concentration in fish ( $f([Hg]|S)$ ) describes a probability density function for mercury concentration that will vary depending on the probability distribution of fish size. Because the estimate of risk is not dependent upon the mercury concentration in fish *per se*, but rather on the mercury concentration in the fish preyed upon by the receptor, this relationship can be rearranged in terms of the likelihood of a receptor ingesting any given concentration or mercury, relative to the distribution of mercury, based on the size of fish most likely to be eaten. Therefore, the prey selection can be substituted for S as follows:

$$\bar{f}(r) = \frac{\bar{f}(IR) \times \bar{f}([Hg]|f(F))}{\bar{f}(t)} \left( \frac{dIR}{dP} \right) \left( \frac{d[Hg]}{dP} \right) \left( \frac{dF}{dP} \right) \left( \frac{dTRV}{dP} \right)$$

where  $f(F)$  is the probability density function for prey selection specific to a given receptor. Information on the derivation of these dependent probability density functions using Bayes' theorem can be found in Gelman et al. (1997). Note that the solution is not dependent upon the summation of distributions but on a dependent probability function. The reliance on the summations of probability, similar to that applied by SFWMD in their probabilistic risk assessments, results in a distortion of the resulting risk function. Probabilistic density functions cannot be summed, especially if they are solved using Monte Carlo methods. Attempts to use summations in such a risk model will result in biasing the estimates towards the mean and therefore underpredicting the proportions of the population at the extremes. Since ecological risk tends to occur in the extremes of the risk function, such an error will result in a dramatic underestimation of potential impacts.

The rate of prey intake may also be described as a probability density function. It is often determined as a variable dependent on the receptor's body mass within a variance between individuals within a population. This may be expressed as follows:

$$IR = a \times \log(BW)^c + e$$

where intake rate (IR) is dependent on receptor's body mass (BW) and the error within the population (e). The coefficients of the equation (a and b) are usually estimates based on experimental observations. One problem with the application of such a model is that other factors within the risk equation cannot also be dependent upon the

receptor's body mass. In this case, it is possible that the response distribution ( $f(t)$ ) may also vary with body mass. To protect against potential correlations, one value must be described as a constant. In this case, the response variable  $f(t)$  was selected to be represented by a toxicity reference value (TRV). This assumption was applied for two reasons: 1) to protect against potential correlations with the intake rate, and 2) the current understandings of wildlife responses to mercury is not sufficient to establish an adequate dose response curve. Therefore, attempts to estimate the probability density function for the response would be highly uncertain.

It is now possible to use a probability density function to represent intake rate because correlation to the response variable is no longer a concern. Using the example of great blue heron and applying the allometric scaling of Kushlan (1978), the distribution of potential intake rates may be included in the risk model as follows:

$$\bar{f}(r) = \frac{(9.66 \times \log(\bar{f}(BW))^{-0.64}) \times \bar{f}([Hg]) \bar{f}(F)}{TRV} \left( \frac{dBW}{dP} \right) \left( \frac{d[Hg]}{dP} \right) \left( \frac{dF}{dP} \right) \left( \frac{dTRV}{dP} \right)$$

where the probability density function for the intake rate has now been replaced with a probability density function for the receptor's body weight. This is the equation that was applied in the evaluation of risk between the high phosphorus AU and low phosphorus AU.

## References

- Fishman, G.S. 1996. Monte Carlo—concepts, algorithms, and applications. Springer, New York, NY. 698 pp.
- Gelman, A., J.B. Carlin, H.S. Stern, and D.B. Rubin (eds). 1997. Bayesian data analysis. Chapman & Hall, London. 526 pp.
- Kushlan, J.A. 1978. Feeding ecology of wading birds. pp. 249–296. In: Wading Birds. A. Sprunt, J. Ogden, and S. Winckler (eds). National Audubon Society, New York, NY.

## **Appendix B**

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### **An Evaluation of Population Risks to Avian and Mammalian Wildlife in the Northern Everglades**

# **An Evaluation of Population Risks to Avian and Mammalian Wildlife in the Northern Everglades**

**Chris Mackay, Ph.D.  
Jenee Colton  
Gary Bigham**

## **Probabilistic Risk Assessment**

- **A method of modeling based on a distribution of potential values**
  - **Values are linked to probability of occurrence**
    - **Distributions can be treated as a variable but with specific caveats (i.e independence, correlation)**
  - **Provides a distribution of potential outcomes along with the probability of their occurrences**
    - **Allows for the risk to be structured in proportional terms**
  - **Permits the retention and parsing of error using Bayesian analysis**
    - **Allows for quantitative uncertainty analysis**

## **Probabilistic Risk Assessment**

- **Components (USEPA 1999)**
  - **Identification of endpoints (hypothesis)**
    - The precise population to be modeled
    - Allowable uncertainty for hypothesis testing
  - **Model**
    - The relation of the inputs to the outputs
    - Must not be implicitly constrained
  - **Input distributions**
    - Representative, justifiable, independent
  - **Risk characterization distribution**
    - Must be symmetrical & address identified endpoints
  - **Uncertainty analysis**
    - The most important component of the analysis
    - Should be quantitative

## **Identification of Endpoints**

- **Receptors of Concern**
  - **Wading birds**
    - Great Blue Heron, Great Egret, Wood Stork
  - **Piscivorous Mammals**
    - River Otter, Everglades Mink
- **Exposure**
  - **Ingestion of fish**
- **Contaminant of concern**
  - **Methylmercury**
- **Endpoint of impact**
  - **Reduced reproduction**

## Risk Model

$$Risk = \frac{Exposure}{Response}$$

$$HQ = \frac{ADD}{TRV} = \frac{IR \times (D \times [X])}{TRV}$$

## Probabilistic Model

$$Risk = \frac{IR \times (A \times S \times C \times [Hg])}{BW \times (TRV)}$$

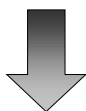


$$\bar{f}(r) = \frac{\bar{f}(IR) \times \bar{f}(A) \times \bar{f}(S) \times \bar{f}(C) \times \bar{f}([Hg])}{\bar{f}(BW) \times \bar{f}(TRV)} \left( \frac{dx}{dP} \right)^7$$

## Integral Model

### Step 1: Proportional Independence

$$\bar{f}(r) = \frac{\bar{f}(IR) \times (\bar{f}(A) \times \bar{f}(S) \times \bar{f}(C) \times \bar{f}([Hg]))}{\bar{f}(BW) \times \bar{f}(TRV)} \left( \frac{dx}{dP} \right)^7$$

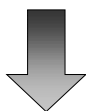


$$\bar{f}(r) = \frac{\bar{f}(IR) \times (\bar{f}_A [\bar{f}([Hg]_{SC})])}{\bar{f}(BW) \times \bar{f}(TRV)} \left( \frac{dx}{dP} \right)^5$$

## Integral Model

### Step 2: Correlation

$$\bar{f}(r) = \frac{\bar{f}(IR) \times (\bar{f}_A [\bar{f}([Hg]_{SC})])}{\bar{f}(BW) \times \bar{f}(TRV)} \left( \frac{dx}{dP} \right)^5$$



$$\bar{f}(r) = \frac{IR}{BW} \frac{(\bar{f}_A [\bar{f}([Hg]_{SC})])}{\bar{f}(TRV)} \left( \frac{dx}{dP} \right)^3$$

## Integral Model

### Step 3: Estimation

$$\bar{f}(r) = \frac{IR}{BW} \frac{(\bar{f}_A [\bar{f}([Hg]_{sc})])}{\bar{f}(TRV)} \left( \frac{dx}{dP} \right)^3$$



$$\bar{f}_A(r)_{A_1}^{A_2} = \frac{IR}{BW \times TRV} \bar{f}([Hg]_{sc}) \left( \frac{dx}{dP} \right)$$

## Uncertainty Analysis

- **Model uncertainty**

- **Does the model represent cause and effect**

- Represent key or rate limiting factors
- Accurately address the endpoints

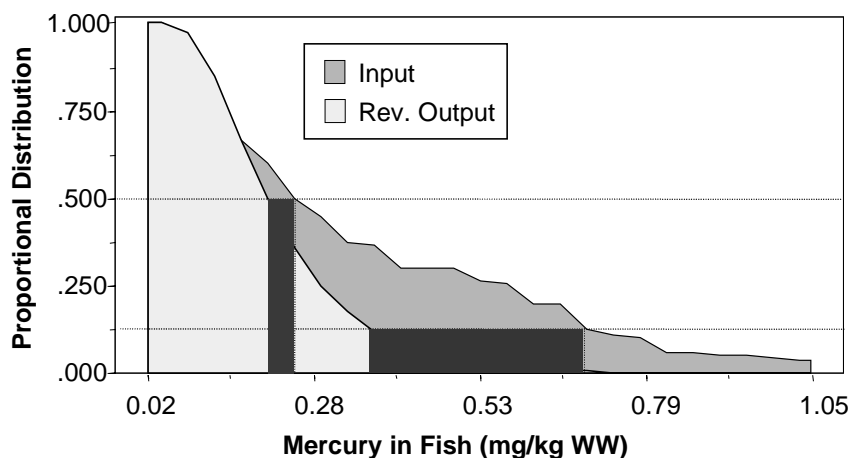
- **Is the model mathematically correct**

- Does the equation hold for all possible values for all distributions
- The equation must be demonstrated to be reversible

## Uncertainty Analysis

$$ADD = (IR \times D_p \times [Hg]_p) \times BW^{-1}$$

Mercury Concentration in GBH Diet: U3



## Uncertainty Analysis

$$\underbrace{\bar{f}(x)}_{\text{Estimated}} = \underbrace{f(x)}_{\text{Actual}} + \underbrace{\epsilon_{est} + \epsilon_{corr} + \epsilon_{exp}}_{\text{Uncertainty}}$$

### • Variable uncertainty

– Difference between the predicted and the actual

- Estimated: Predictable variance based on data availability and applicability
- Correlation: Variance based on changes in the relation with magnitude
- Experimental: All identified variance not accounted by known sources

## Input Distributions

$$\bar{f}_A(r)_{A_1}^{A_2} = \frac{IR}{BW \times TRV} \bar{f}([Hg]_{SC}) \left( \frac{dx}{dP} \right)$$

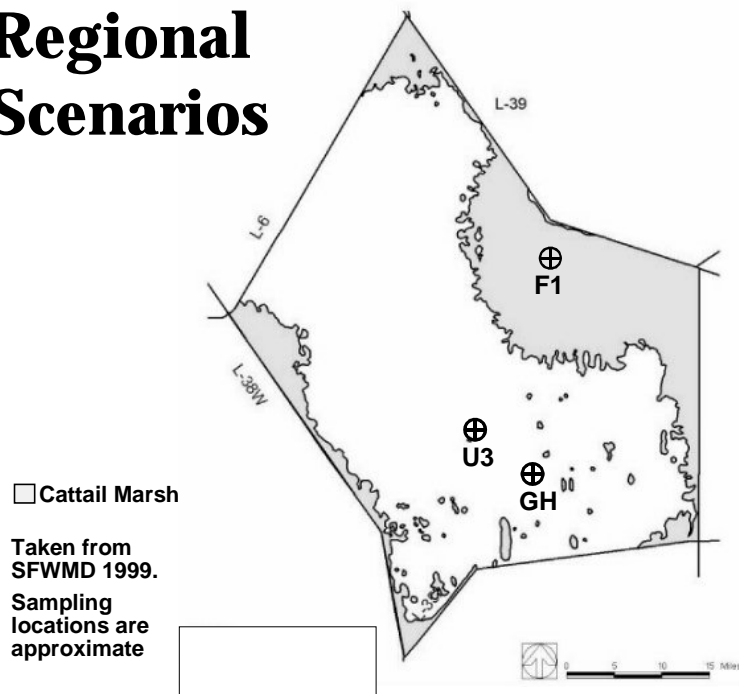
- **Scenario Variables**
  - High P vs. low P regions
- **Determinant variables**
  - Body weight, intake, TRV
- **Probabilistic Variables**
  - Mercury concentration in diet

## Determinant Parameters

- **Response to mercury (TRV)**
  - 0.032 mg/kg-day (SFWMD)
- **Body weight (BW); Intake Rate (IR)**
  - Wading birds: -SFWMD
  - Mammals: - Various

Species	kg/kg-day	kg
G. Blue Heron	0.139	2200
Wood Stork	0.139	2400
Great Egret	0.143	1000
Everglades Mink	0.297	646
River Otter	0.047	7900

## Regional Scenarios



## Prey Distribution: $f(SC_{[Hg]})$

- Diet is a function of both habitat and predator attributes

### Habitat Attributes

Relative abundance  
Size cohorts ?  
Prey diversity ?

### Predator Attributes

Foraging behavior ✓  
Size limit ✓  
Prey refusal ✓

## Prey Distribution: $f(SC_{[Hg]})$

- Diet is a function of both habitat and predator attributes

### Habitat Attributes

- X Relative abundance
- ? Size cohorts ?
- ? Prey diversity ?

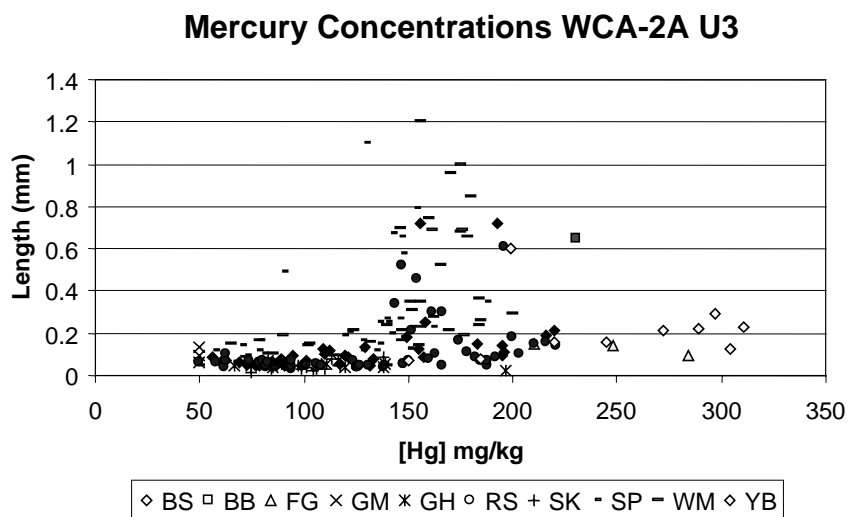
### Predator Attributes

- ✓ Foraging behavior ✓
- ✓ Size limit ✓
- ✓ Prey refusal ✓

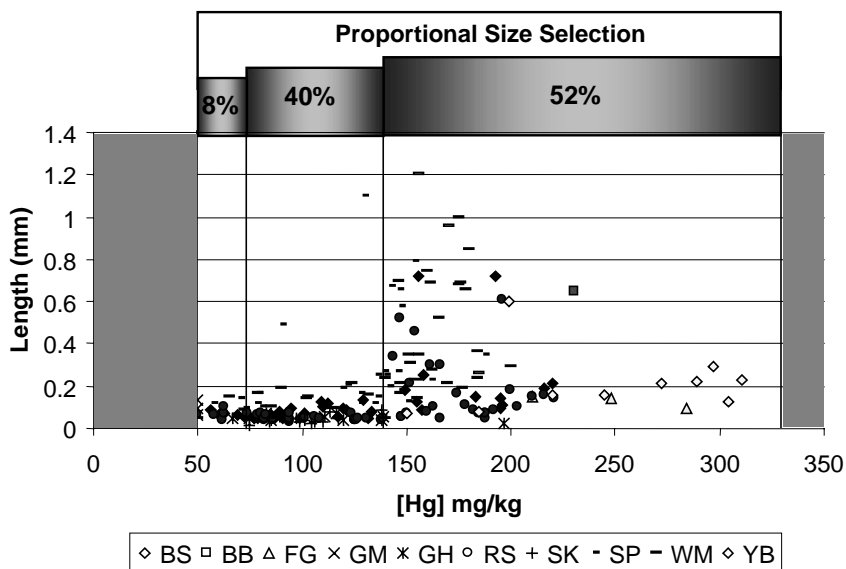
## Prey Distribution: $f(SC_{[Hg]})$

- Prey size selection
  - Assume 100 % fish diet
  - GLWQI 1995, Frederick, Kushan, WEFH, etc.
- Fish species abundance
  - Babbit and McIvor: Wet prairie slough
  - Lange: Northern Everglades/STRs
  - Frederick: Based on frequency in egret diet
- Mercury Data
  - Lange, SFWMD, ACME
    - Limited to 1996-1998
    - U3/GH: n = 200
    - F1: n = 35

## Mercury Distribution



## Prey Selection: Size: GBH



## Prey Distribution: $f(SC_{[Hg]})$

Species	Overall	5-7 cm	7-14 cm	14-33 cm	Length
Total	100%	8%	40%	52%	P(size)
<i>Gambusia sp.</i>	98.12%	97.64%	0.00%	0.00%	P(Species)
<i>L. punctatus</i>	1.30%	2.16%	80.37%	72.64%	
<i>L. gulosus</i>	0.15%	0.05%	5.64%	16.32%	
<i>F. seminolis</i>	0.11%	0.00%	4.47%	0.00%	
<i>N. crysoleucas</i>	0.09%	0.03%	3.03%	0.00%	
<i>Am. nebulosus</i>	0.08%	0.00%	0.00%	0.16%	
<i>Am. natalis</i>	0.08%	0.00%	0.00%	3.57%	
<i>L. microlophus</i>	0.04%	0.07%	3.76%	4.91%	
<i>L. macrochirus</i>	0.03%	0.06%	2.73%	2.73%	
<i>Lepisosteus sp.</i>	0.01%	0.00%	0.00%	0.11%	

## Prey Distribution: $f(SC_{[Hg]})$

$$\begin{aligned}
 & \left( P_{C_1} \quad K \quad P_{C_N} \right) \times \begin{pmatrix} P_{S_1} \\ M \\ P_{S_N} \end{pmatrix} \div \begin{pmatrix} n_{C_1 S_1} & \Lambda & n_{C_N S_1} \\ M & & M \\ n_{C_1 S_N} & \Lambda & n_{C_N S_N} \end{pmatrix} \\
 & = \begin{pmatrix} \theta_{C_1 S_1} & \Lambda & \theta_{C_N S_1} \\ M & & M \\ \theta_{C_1 S_N} & \Lambda & \theta_{C_N S_N} \end{pmatrix}
 \end{aligned}$$

**Bayesian Matrix**

## Prey Distribution: $f(\text{SC}_{[\text{Hg}]})$

Where  $P_{\text{SC}} \equiv \theta_{\text{SC}_x}$

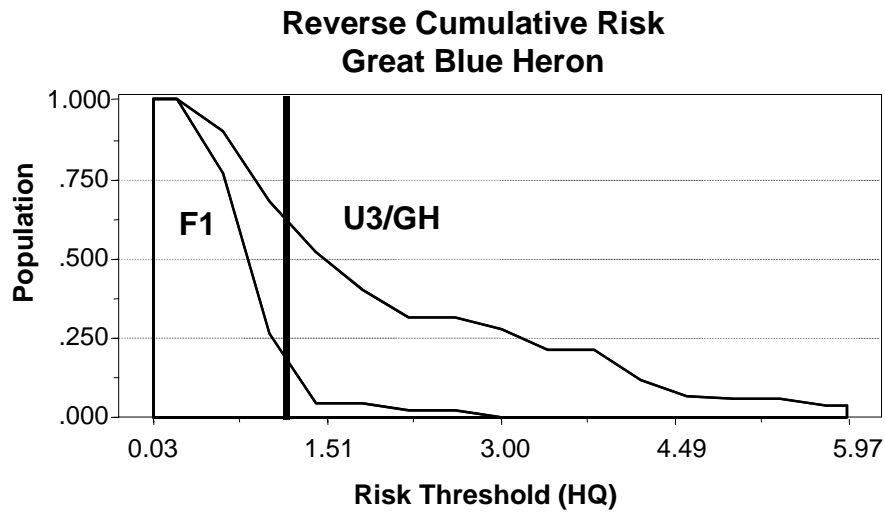
$$\begin{aligned}\theta_{\text{SC}_x} &= \frac{P_{C_x} \times P_{S_x}}{(P_{CS} | P_{SC})} \\ &= \frac{P_{C_x} \times P_{S_x}}{n_{CS} \times \frac{P_S}{n_{SC}}}\end{aligned}$$

## Prey Distribution: $f(\text{SC}_{[\text{Hg}]})$

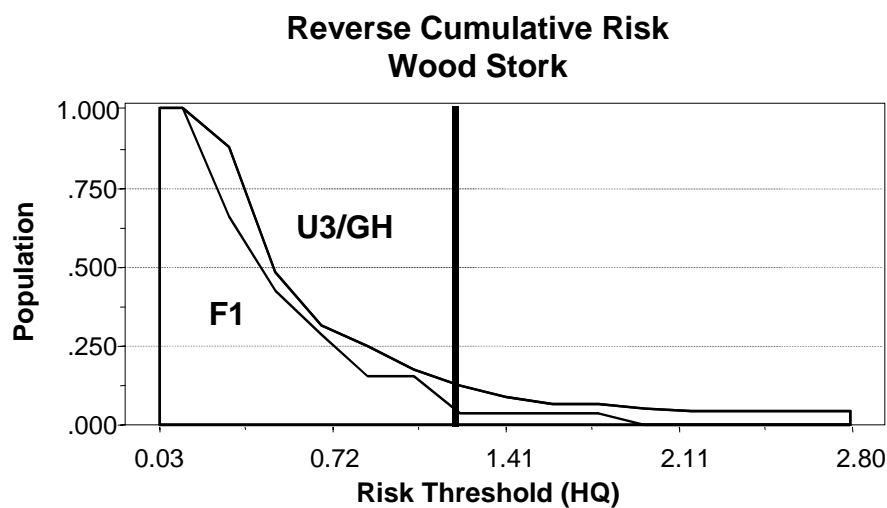
$$\bar{f}([Hg]_{\text{SC}}) \equiv P^*(\theta_{\text{SC}_x} | [Hg]_{\text{SC}_x})$$

### Distribution-Free Jackknife Bootstrap

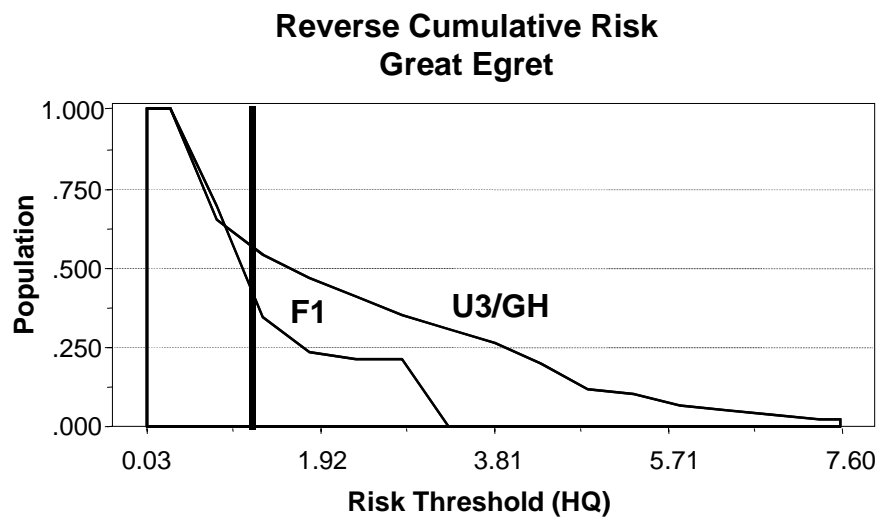
## Risk: Great Blue Heron



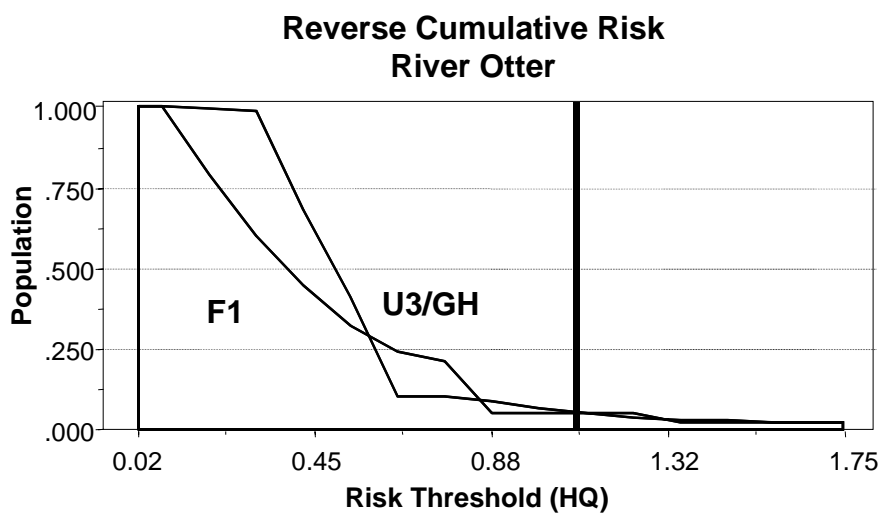
## Risk: Wood Stork



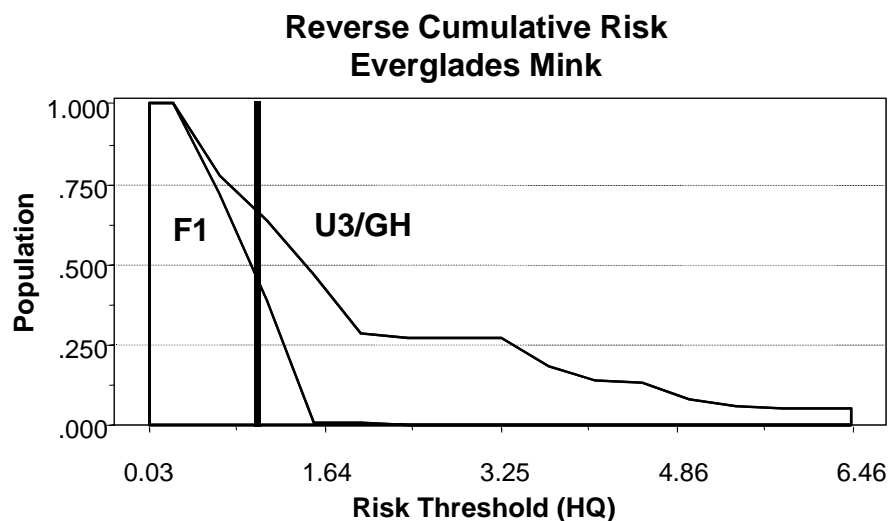
## Risk: Great Egret



## Risk: River Otter



## Risk: Everglades Mink

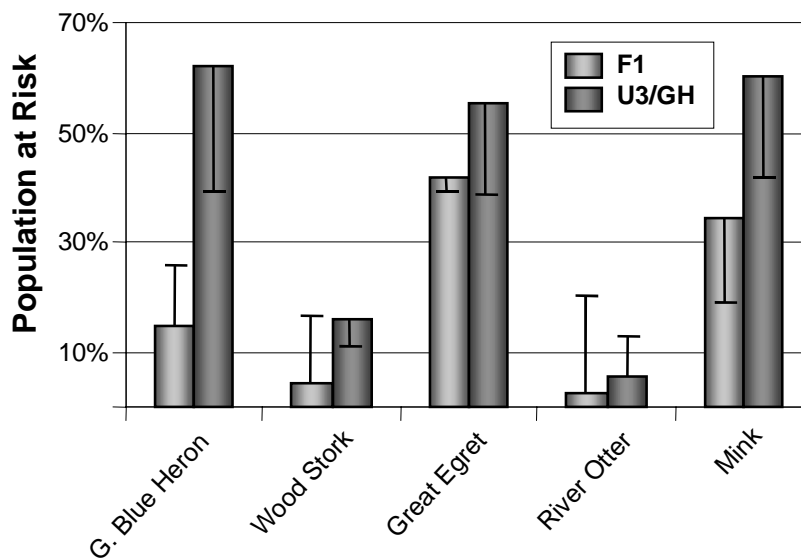


## Comparative Risk

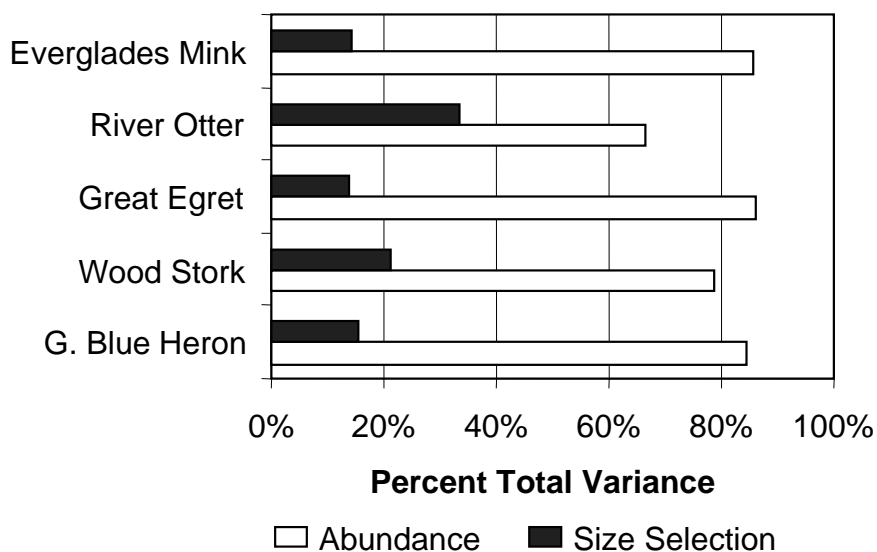
Percent Population at Risk

Species	F1	U3/GH
G. Blue Heron	14.61%	62.26%
Wood Stork	4.09%	15.84%
Great Egret	41.59%	55.50%
River Otter	2.66%	5.69%
Mink	34.61%	60.23%

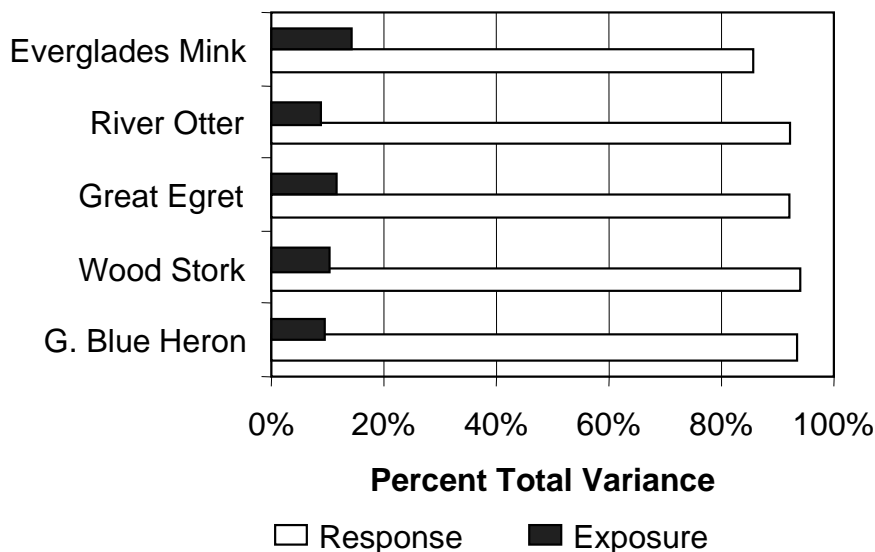
## Uncertainty: Model Analysis



## Uncertainty: Variable Analysis



## Uncertainty: Variable Analysis



## Conclusions

- **High P regions represent lower mercury risk than low P regions**
  - GBH > Mink > G. Egret > W. Stork > R. Otter
- **Greatest impact will occur in the earliest stages of the restoration**
- **Uncertainty in prey species requires more data on fish abundance and diversity in both high and low P environments**